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SARDAR VALLABHBHAI PATEL LECTURES

New Era of Science

K. S. KRISHNAN

SECOND SERIES

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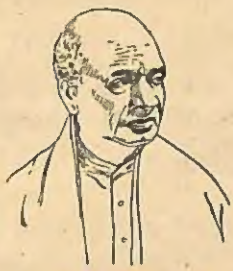
K. S. KRISHNAN

THE NEW ERA OF SCIENCE



SARDAR VALLABHBHAI PATEL LECTURES

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PREFACE

The Sardar Vallabhbhai Patel Lectures were instituted by All India Radio in 1955 as an annual feature. Each year's lectures are given by an eminent authority and are designed to stimulate interest in contemporary problems.

Shri C. Rajagopalachari inaugurated the series in 1955. His address has been published by the Publications Division under the title "The Good Administrator".

The second year's lectures, delivered by Dr. K. S. Krishnan in October, 1956, have been brought together in the present book.

I DEEPLY appreciate the honour of being invited to give this year's Sardar Patel Memorial Lectures. I wish to thank sincerely the organisers for giving me this opportunity to pay my tribute to the memory of one of the greatest statesmen that modern India has produced. The title of these lectures is "The New Era of Science" in which, naturally, we are all interested, whether our direct interests lie in science or elsewhere.

The recent outburst of cultural activities—the numerous seminars, conferences and exhibitions—organised in Delhi and elsewhere in connection with the Buddha Jayanti celebrations has tended to highlight one major trait that characterizes all living ancient civilizations like ours, namely, the remarkable resilience that they have shown all through the ages, and the capacity for absorbing and assimilating newer and widely different currents of thought. Otherwise these civilizations would not have survived so long. We were of course aware of this trait previously, but the recent seminars have brought it to light rather prominently. Sanskrit scholars have a felicitous way of expressing this resilience. The word पुराणा: (puranah) means literally "the ancient ones" but the scholars, taking advantage of the elasticity so peculiar to the language, have taken the word to mean पुरापि नवा: (purapi navah): that is, "more fresh than ever before," which again serves to emphasize the peculiar genius of our civilization to assimilate and integrate many different cultural currents; realizing "unity in diversity" has luckily been one of our major virtues.

This virtue, which is so eminently characteristic of our cultural life, has unfortunately not been so apparent in our political life. Indeed at many stages in our long political history, this virtue has been conspicuously absent. Even in the golden age of Asoka, to which we all refer with a certain pride, the integration of the country was predominantly cultural rather than political. Real integration, extending not only over the cultural but also over other fields, is of a more recent date. At any rate its sturdy growth is recent and it had to await the nurturing care with which Mahatmaji and his distinguished colleagues cherished them. It is, therefore, not without significance that we fondly refer to him as the Father of the Nation. The accomplishment of this task of integration of the country on the political side was in a large measure that of Sardar Patel, whose anniversary we are commemorating today.

There is close analogy between the virtues involved in cultural integration and those needed for the cultivation and advancement of the pure sciences, and similarly between those involved in political integration and in technology. In this context it may be significant that in India we took to the pure sciences much more readily than to the applied sciences. With our great cultural and academic traditions and the new political awakening, one may confidently look forward to a bright scientific and technological future for the country.

Now the main purpose of science is to understand Nature in all her varied aspects, and learn to control Nature and to use this mastery over Nature for the good of mankind. I am aware that even the mere mention of 'control over Nature' brings immediately to one's mind its misuses too, some of them frightfully inhuman. Indeed when I was

thinking of a suitable title for these lectures I thought of "The Atomic Age", but for the reason just mentioned I fought shy of using it. I know also that many people who are not quite sympathetic to science have asked the question: "Why then apply science at all if its results are liable to be so grossly misused?" They would quote very eminent authorities too. The well-known toast for science is: "Here is to science. May it be of no use to anybody at any time." The great mathematician Gauss, who would rank with Archimedes and Newton as one of the greatest mathematicians the world has ever produced, is reported to have said that if mathematics may be regarded as the Queen of the Sciences, then the theory of numbers should be regarded as the Queen of Mathematics—and he proceeded to give the reason—"because it is the least useful". But the reply to these critics would be this: The ideal of knowledge for its own sake is a very ancient one, at least as old as Plato. It is also a laudable one, and has proved to be of immense value. This Platonic ideal has inspired creative thought over all the intervening centuries in many centres of learning. It expresses the natural yearning of the creative artist to be left alone without being bothered by interference from those he would regard as the Philistines.

I may be permitted a digression here. As some of you know, what are now called non-Euclidean geometries were developed about the middle of the last century by two or three independent groups of mathematicians. It is a typical example of a problem which had resisted the attack of very able mathematicians for more than two thousand years, and for which, very strangely the solution was found almost simultaneously by two or three independent groups of workers. Gauss certainly had the solution, probably earlier, but questioned why he had not

published the solution he made the characteristic reply that he feared the outcry from the Boetians. In the context, Gauss was obviously thinking of the Boetians among the mathematicians themselves, and not of the uninitiated multitude.

I permitted myself this digression just to emphasize that when Gauss claimed for the theory of numbers the unique virtue of "being the least useful" he was merely voicing forcibly the traditional distinction between the arts and the crafts, between knowledge for its own sake, *i.e.*, knowledge that is not usable and which for that reason was regarded as high-brow knowledge, and knowledge which is applicable. It was a distinction nearly as marked as the distinction between Gentlemen and Players at Lord's. Intellectual aristocracy is not peculiar to any one country or climate. I would remind ourselves at this stage, lest we feel very superior, of a proverb which is probably Sancho Panza's—that wisdom may not be all ancient nor is all folly outdated. There is hardly any branch of mathematics, however abstruse, which is not applicable. At a conference of mathematicians nearly twenty-five years ago, the question was pointedly raised, probably in the context of Gauss's claim for the theory of numbers that it is the least usable, whether for example the theorem of partition of numbers found any practical application. Presumably the questioner regarded it as the least likely of application among the results in number theory itself. The answer was, surprisingly, affirmative, and came from one of the scientists in the Bell Telephone Laboratories who had been applying it effectively for his work on the splicing of cables. There are two research papers on this subject in the Bell System Technical Journal to which I may refer the reader if he is interested.

I mentioned just now that there is hardly any branch of abstruse mathematics which is not ultimately applicable. In the same manner almost any result in science which is applicable for the good of mankind can probably be equally effectively misused. "Belligerency," as David Sarnoff remarked, "is an attitude of mind and not a property of matter and therefore does not concern science as such." The cure for misuses of science is to stop the misuses, and not to stop all the uses of science. It would be like throwing out the baby along with the bathwater. Blackmailing, for example, might be a form of telling the truth but we do not for this reason think the less of the virtue of truthfulness.

I may add incidentally that the corresponding Sanskrit word "satyam," so dear to Mahatmaji, has always been regarded as excluding misuses. सत्यं यथा दृष्टार्थं । हितरूप वचनम् । (Satyam yathadrishtartham hitaroopa vachanam) is an old definition of the word, *i.e.*, "The content should conform to the best of one's personal knowledge, and its expression such as would conduce to the good of humanity." It is unfortunate that one has to use the same respectable word "science" even when it is grossly misused. It reminds me of a well-known Tamil classic in which the author deplores that the cultured and the vandals have the same external animal appearance.

Most of the sentiments expressed by the ancients about the control of the senses and of the temptations are applicable to the proper uses and the misuses of science. The ancient teachers insisted on strict disciplining and proving of character of the disciples before they ventured to impart any knowledge, particularly knowledge of profound import: though it might imply monopoly of available knowledge, and might as such be itself misuse, the basic

principle underlying it might be of value even today—probably I should say particularly today.

Rajaji, my very distinguished predecessor on this platform—you may remember he initiated the Sardar Patel Memorial Lectures last year—has a modern rendering of this safeguard. It was not in his Patel Lectures, but elsewhere when he was in one of his characteristic Jules Vernian moods. What we need for the purpose is a gadget for monitoring the operations of the human mind and the moment it recognises the image of an evil thought fleeting across the field of view, the monitor will operate a relay that will automatically freeze all further thinking and immunize the brain.

"To ask well is to know much" is an old proverb. All our great epics start with someone asking such a question. प्रपच्छ is a hoary word. The demand made of our gadget is one such. It implies that it is in the minds of men one should seek a solution. It is not a problem in the physical sciences, but one concerning the human mind. After attending some of the sessions of Unesco, one almost hears the words of the first paragraph of the Declaration, namely, "Since wars begin in the minds of men, it is in the minds of men that the defences of peace must be constructed."

I said that the major objective of science is to understand Nature. It immediately implies a certain faith, which, however, has since been wholly justified by our wide experience, that underlying the working of Nature and the operation of all natural phenomena there is a certain inherent order, and conformity to certain invariable and fundamental physical laws. Nature, as Einstein remarked, may be profound, but she never cheats, that is, she plays the game strictly according to the rules. The

rules of course are of her making but she never changes the rules to suit the vicissitudes of the game. There are no exceptions to these rules. The main purpose of science is to discover these fundamental laws of Nature, to unveil the ultimate pattern to which natural phenomena, and all the events in Nature, conform. In this sense the function of science is more one of unveiling than one of creating.

A preliminary to it, or an essential first step towards it, would be a detailed study of natural phenomena, either in the fields, or in the laboratory under controlled conditions, in which the parameters that are likely to influence the phenomenon, and which are usually many and complex, can be varied one at a time. The major incentive at this stage is one of curiosity in which every new phenomenon presents features of interest, and the traveller manages incidentally to accumulate a large amount of new knowledge. In the wealth of detailed information that accrues in this process of voyaging, he may not see the wood for the trees, but each tree is a novel type which attracts him. He may find numerous empirical rules, and many regularities in his data, but they do not yet piece together into a single coherent whole. This stage corresponds to what the great philosopher and educationist Professor Whitehead would regard as the stage of romance in the education of a child.

The next stage is one of synthesis, of trying to find the pattern into which all the observational data can be fitted elegantly. This is the stage of accurate measurement and rigorous disciplining. "Through measurement to knowledge" is the motto of a famous laboratory which did much of the pioneering work on the properties of substances at very low temperatures. Because after all it is the precise quantitative fit of the different quantities that

are related to one another that gives science that great security which it would not otherwise be able to attain.

I mentioned just now the quantitative fit of quantities that are related to one another. This relation is naturally expressed in the form of a simple mathematical formula and the quantitative fit amounts to a precise verification of it. It immediately raises a fundamental question. Mathematics, as we all know, starts with certain fundamental axioms, and builds on the basis of these a logical structure. Taking for example Euclid's *Elements*, we do not know how much of the knowledge contained in the available books of Euclid is his own, and how much of it is a codification of the then available knowledge. Starting from the axioms, with which we are all so familiar, the logical sequence in which the different propositions follow is presumably Euclid's own. Each proposition follows logically and inevitably from the propositions that have preceded them, and the latter in their turn are based ultimately on the axioms. Fontenelle compared mathematicians to lovers. "Grant a mathematician the least principle, and he will draw from it a consequence which you must also grant him, and from this consequence another," until you find that you have conceded him all the thirteen books of Euclid or those that are happily left of them. A fundamental question that I referred to is this. It has been posed by many philosophers. I shall quote it in the form in which it has been raised by Einstein. "How can it be that mathematics, being after all the product of human thought independent of experience, is so admirably adapted to the objects of reality ?"

Indeed he goes much further and declares that the creative principle resides in mathemtics—I am quoting him now—"and in a certain sense therefore I hold it true that

pure thought can grasp reality as the ancients dreamed". In the context of the profound issue raised, you will appreciate my quoting Einstein on this issue rather than the lesser philosophers. After all physics is natural philosophy and has been so designated for quite a long time. One can also appreciate the earlier reference to mathematics endowing the sciences with a certain security which they would not be able to attain otherwise.

It is a fundamental corollary to all mathematics that you cannot draw out from it more than you have put into it in the form of the axioms. In a sense the cleverness of the mathematician lies in his smuggling into his axioms essentially all that he wishes to prove elaborately later on. It is like the magician producing the kerchiefs in large numbers. They have been there all the time, only we did not realise it earlier.

In this context the amazing appropriateness of mathematics for dealing with problems of reality can be traced ultimately to the reality of its axioms, which are products of human experience, and therefore conform to Nature.

I do not propose to answer in detail the further question that would be raised immediately: how far the external world that we see is real, or is ultimately merely a product of human thought. The answer is that it is real in the same sense in which the axioms of geometry which are the result of human experience with the external world are real. But I shall not try to justify my answer. I would leave it to the metaphysician. It is really his province.

Now the supreme adaptability of mathematical formulae to natural phenomena naturally secures for mathematics a pre-eminent place in the explanation of natural phenomena.

It is almost an article of faith among physicists that the ultimate pattern with which all observable data can be fitted is presumably a simple and elegant one. If so, the simple and elegant mathematical formulae should find repeated application in physics: this faith has been amply justified by experience. The partial differential equations are a striking example. I prefer to base my illustrations on physics, since I am closer to this discipline than to the others, but the conclusions are typical, and would apply to all other disciplines too. One has merely to turn over the pages of some of the classical treatises on physics like Kelvin and Thomson's *Treatise on Natural Philosophy*, or Maxwell's *Treatise on Electricity and Magnetism* or Lord Rayleigh's *Theory of Sound*, or Lamb's *Hydrodynamics*, or Routh's *Analytical Mechanics*, or Love's *Theory of Elasticity*. One will meet the same faces, the same veterans who have been through many an old campaign and have, of course, survived. Among them the partial differential equations are the most familiar ones. Indeed their ubiquity is so striking that Einstein was forced to remark that the partial differential equations first came to theoretical physics as a servant, but by degrees became its master. Among the numerous publications of Eric Bell on mathematics are two entitled *Mathematics the Handmaid of the Sciences* and *Mathematics the Queen of the Sciences*. I do not remember which of these two appeared first. But as a physicist I have no doubt in which capacity mathematics stays ultimately in physics—always as the Queen. Hertz, speaking of the famous electromagnetic equations of Maxwell, remarks: "One cannot escape the feeling that these mathematical formulae have an independent existence and an intelligence

of their own, that they are wiser than we are, wiser than even their discoverers, that we get more out of them than we put into them." These are strong words indeed, but come from one who first demonstrated in the laboratory the real existence of the electro-magnetic waves that are lurking in a Maxwell's equations, and who in that sense gave a real body to those equations, and who therefore knows what he is talking about, and who was, further, very sparing of his words.

The prominent position of mathematics is even more strongly illustrated by the position in which physics found herself not so long ago. Three very young men, all in their twenties, all of them extremely competent theoretical physicists, gained such control over the progress of physics that the physics of their period was referred to almost adoringly as Knaben Physik, *i.e.*, physics created by boys. I remember the then Secretary of the British Association telling a story which was of great topical interest then. At a meeting of the British Association Lord Rutherford was to give one of the evening lectures. 'Modern Trends in Physics' was suggested to him as a suitable subject for the lecture. Rutherford replied in a light vein: "I can't make that the subject of a whole lecture. I can say all that in two sentences. The theoretical physicists have all got their tails up, and it is up to us, the experimenters, to pull them down by their tails." Coming from one who not only had immense regard for the theoretical physicists but also supplied most of the meat for theoretical physics, the remark of Lord Rutherford serves merely to emphasize the position physics found herself in. I am sure he was as proud of Knaben Physik as the boys themselves.

Thus the second stage in the development of science is the one of synthesis or consolidation or integration, and the main objective is to find the appropriate mathematical pattern in which all the available data can be satisfactorily fitted. As in solving a cross-word puzzle, when one happens to hit on the right solution all the facts fall in their place so readily and effortlessly. It is indeed the most dependable criterion of the validity of a theory. I shall quote just one typical example from the work of Maxwell, and in the sublime words of Boltzmann, who compared this part of the work to a musical drama—the adjective 'sublime' which I used just now is that of Planck: you may judge its appropriateness yourself—"At first one developed majestically the variations of the velocities, then from one side enter the Equations of State, then from the other Equations of Motion in a central field; ever higher sweeps the chaos of Formulae: suddenly are heard the four words: 'put N =5'. The evil spirit V (the relative velocity of two molecules) vanishes and the dominating figure in the bass is suddenly silent; that which had seemed insuperable being overcome as if by a magic stroke. There is no time to say why this or why that substitution was made; who cannot sense this should lay the book aside, for Maxwell is no writer of programme music, who is obliged to set the explanation over the score. Result after result is given by the pliant formulae till, as unexpected climax, comes the heat equilibrium of a heavy gas; the curtain then drops."

The next stage in the progress of the science is that of generalization. The mathematical pattern that was found to fit all the observational data in the selected field is found to have a much wider significance, and is equally well applicable to other fields too.

Obviously it is these two later stages that endow the sciences with their essential unity. Otherwise we shall have just a heap of uncorrelated and innumerable facts. They are just the building stones. The beautiful edifice that emerges ultimately is naturally so different from the heap of stones that went into them that one may now almost forget the stones. It is like what the ancients call wisdom, rising above the details of knowledge.

I shall illustrate with a few striking examples, again from physics. Before Newton there had naturally accumulated an enormous amount of observational data on the mechanics of bodies, particularly on the motions of the planets. When once Newton had formulated his well-known laws of motion and the law of gravitation, all these observational data get fused into these simple compact laws. When required, one can obviously reproduce these data, *i.e.*, calculate back the data from these basic laws of mechanics. Indeed the simplification of the whole field of mechanics was so dramatic and the transformation was done so effortlessly that a very distinguished historian could refer to this in just two sentences, very different from Rutherford's, of course: Newton said "Let there be light" and "there was light". It looked that simple.

The events that preceded the formulation of the theory of relativity are equally romantic. There were numerous experiments performed which, in effect, though not always actually, were attempts at measuring the absolute motion of earth through space. Surprisingly, as judged against the then available scientific background, all the experiments were a failure. They gave completely negative results. An *ad hoc* explanation was offered in each case, and when the defects were rectified and the experiments

were redesigned, they still persisted in yielding just negative results; until finally Einstein made the simple postulate that we are probably trying to measure something which is not measurable at all, even in an idealized experiment in thought, in which human and instrumental imperfections have been completely eliminated. It may be one of those quantities which we have come to designate as unobservable in physics.

Starting from this postulate one can draw many logical conclusions; just as one builds up his geometry from the axioms, one gets an entirely new picture of the fundamental physical concepts like mass, inertia, and even of the velocity of propagation of light in vacuum. I shall select just one of them for special mention here, namely, the equivalence of mass and energy and their interconvertibility which has formed the basis of generation of power from nuclear fission and fusion. Just as Faraday's discovery of electromagnetic induction may be regarded as having initiated the electrical age, the recognition of the convertibility of matter into energy, which is sometimes referred to as the etherealization of matter, has sponsored the age of atomic energy. Thus on one side science is expanding rapidly into numerous new fields, and new knowledge is accruing at a rapidly increasing rate which makes science more and more complicated; and on the other side the consolidation and integration are also proceeding rapidly, making science simpler and more tractable. I shall speak about these two competing processes in greater detail in my next lecture.

I wish to spend the remaining few minutes in giving just one example in which these two competing processes are very well exemplified. It was realized several years ago that the nuclei of all atoms may be regarded as built

up of two fundamental particles, namely, the protons and the neutrons, both of which have nearly the same mass, but one of which is positively charged and the other is neutral. With the two in appropriate numbers one can build the requisite total mass and the requisite total charge of any given nucleus. The question arises as to how these two types of particles could be held together so strongly as they are found to be. None of the known mechanisms could explain such a strong interaction between them. Following the analogy of interaction between the charged particles, namely, through the electromagnetic radiation field, which may also be regarded as being effected through the exchange of protons or light particles between protons and neutrons, Yukawa found that if the interaction between the two types of particles is due to such exchange, the new particles concerned in such an exchange should have a mass intermediate between the masses of the electron and of the proton. This intermediate particle has since been called the meson.

A new particle answering to this description was later found, which was very gratifying. It was soon realized, however, that though this new particle had some of the requisite properties, it was not quite the one that was wanted. The right one has since been discovered, but meanwhile a large number of other particles too have appeared in the field. Thus while on the one side the explanation of the nuclear forces has been accomplished, we find ourselves saddled with a number of new particles for which at present we have no place in our scheme of things. This is typical of the two processes that have been going on side by side all the time in physics, one tending to expand the subject, and the other tending

to consolidate and simplify the subject. I shall have more to say on these in my next lecture.

II

I REFERRED in my last lecture to the two major tendencies in the development and progress of sciences: (*a*) the rapid accumulation of new knowledge, and the expansion into new, unexplored territories which naturally tend to make science more extensive and more complicated; (*b*) the integration or synthesis or consolidation that is going on side by side which naturally tends to make the sciences simpler and more comprehensive. I shall immediately proceed to explain why I lay emphasis separately on these two tendencies.

It was not so very long ago—not even seventy years—that even the working scientists thought that all the major discoveries in science had already been made, and all that was left for the future generations of scientists to do was to give the finishing touches, like removing some of the angularities, rectifying the anomalies, improving the various techniques, developing newer and more accurate measuring instruments, and pushing the precision of the measurements to the next decimal place.

Even the more progressive among the scientists, who repeatedly emphasized that it was unwise to set limitations to the possibilities of science, had in view discoveries based on more refined techniques, rather than conquest of new fields. I shall illustrate the type of new discoveries they had in view by two typical examples. Extensive measurements had been made on the direction and the magnitude

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of the magnetic field of the earth at various observatories. As you probably know, the earth's field is not precisely in the north-south direction and there are other deviations too from an ideal distribution that one should expect on the basis of the earth's being a uniformly magnetized sphere.

The great mathematician Gauss, to whom frequent references were made yesterday, made a detailed and precise analysis of these magnetic constants observed at different places on the surface of the earth. Even the mathematical technique of the analysis was Gauss's own, and has since found extensive applications in many other fields. From such an analysis he came to the surprising conclusion—this was more than a century ago—that the bulk of the magnetism observed at the surface of the earth, to be more precise, 94 per cent of it, should be attributed to sources located underneath the surface of the earth and the remaining 6 per cent equally definitely to causes located outside.

With the supreme confidence so characteristic of him he marched much farther than any mathematician or physicist of his day would have ventured. He proposed a probable mechanism outside the surface of the earth for accounting for this residual 6 per cent of the observed magnetism. The mechanism that he proposed would have been considered impossible by lesser men than Gauss on the basis of the then available knowledge. The mechanism that he postulated was electric current in the upper regions of the earth's atmosphere. The atmosphere was known to be a good insulator for electricity, and hence incapable of sustaining any electric currents.

But Gauss's confidence in the genuineness of the residue of 6 per cent should have been uncanny to induce

him to postulate such a current. I shall quote his own words, to enable you to realize this. Before doing so I hasten to add that we know today that Gauss was right.

This is what Gauss says : "If we seek for the immediate causes, partly or wholly, without the earth, and confine ourselves to known scientific grounds, we can only think of galvanic current. But the atmosphere is no conductor of such currents, neither is vacant space; thus in seeking in the upper regions for a vehicle of galvanic currents we go beyond our knowledge. But our ignorance gives us no right absolutely to deny the possibility of such currents ; we are forbidden to do so by the enigmatical phenomenon of the Aurora Borealis, in which there is every appearance that electricity in motion performs a principal part." How many birds at one stroke ! Particularly when his contemporaries knew that the birds were not there. We know today that it is these charged layers in the upper regions of the atmosphere that make all long-distance radio propagation possible ; indeed the radio waves can travel several times round the earth under favourable conditions, because of the presence of these ionized layers in the upper atmosphere.

I shall just mention in passing one other discovery which arose out of refined measurements. Lord Rayleigh made some systematic and accurate measurements on the density of nitrogen gas prepared from different sources. He found a small but persistent difference between the density of nitrogen isolated from the atmosphere, and that obtained from chemical sources, which pointed to the probable presence of an impurity in his atmospheric nitrogen which his method of isolation from the atmosphere had not been able to eliminate.

The result, as we all know, was the discovery of argon, and of several other rare gases which have since been assigned a unique and in some respects an honoured place in the family of elements. The clue to the presence of heavy hydrogen came the same way; though later it turned out that the original density measurements which gave the clue were not correct.

The examples which I cited just now are typical of what the scientists at the end of the last century thought was left over for future generations to do. Professor Millikan, who attended the 1893 session of the British Association for the Advancement of Science, records that "an eminent physicist rose to address the assembly, and spent his time giving thanks that he had lived to see the completion of the great edifice of physics." What a comforting thought!

It reminds me of a king who tried to learn cosmology, and when he found the mathematics beyond his comprehension, wished that he had been present at the creation; he could have given useful advice which might have resulted in the creation of a world much simpler and more easy of comprehension than the one we find ourselves in.

The complacency that I have been trying to describe by these examples happened of course to be the calm before a storm. About the same period, Kelvin gave one of the evening lectures at the Royal Institution in London under the title "Clouds over Nineteenth Century Physics" and even he could not have realized the tremendous downpour that was to follow soon after and does not by any means look stopping even now.

The year 1895 witnessed the discovery of X-rays, and of radio-activity, to be followed soon after by the discovery of the electron, the postulate of the quantum theory and

the theory of relativity ; quantum mechanics and wave-mechanics, and the litter of new fundamental particles. We have now with us some antiparticles too. All these are happening at such a terrific rate that even the most serious physicist is completely swept off his feet in this torrent.

In my giving the chronology of the great events, I have naturally given a more prominent place to the work of consolidation than to actual accumulation of new knowledge. In order to emphasise the rate at which new knowledge is accruing, I wish to mention immediately that it is enormously more rapid than the work of consolidation. I am speaking in the language of the schoolboy who after hearing his companion dilate on the many good things in his village merely replied that in his own village they had all these good things and many more. Having mentioned the impressive theoretical advances I shall merely add that on the experimental side the advances are naturally more extensive.

There are many strong reasons for the process of consolidation not keeping pace with the accumulation of new knowledge. A single striking new observation may open up new and almost limitless vistas. I shall mention just one such. The hydrogen atom, which as you know, is the simplest among the atoms, consists of a proton which is positively charged, in which the mass of the atom is practically concentrated, and an electron revolving round it at some distance from it. Now both the proton and the electron of the hydrogen atom are spinning. There is a restriction imposed on these two spins by the requirements of the quantum theory, namely, that the axes of the two spins should be oriented either parallel to each other or anti-parallel. Depending on whether they are

parallel or anti-parallel, the atom has slightly different energies.

Taking the spin axis of one of them as reference, as the axis of the other flicks from one of the permitted orientations to the other, there is either absorption or emission of a quantum of energy whose magnitude can be readily calculated. It corresponds to radiation of about 14·21 megacycles per second, or a wave-length of about 21 cms. A radiation of this frequency is being received from interstellar space, which shows that hydrogen is present there in appreciable quantities.

Now one can take the intensity of this radiation as a measure of the density of the hydrogen atoms present. Further the observed radiations have not quite the frequency to be expected of them which shows that the radiating hydrogens are not at rest but are moving, the difference between the two frequencies being a measure of the velocity of the radiating atoms along the line of sight. Taking the density and the velocity of the motion of the hydrogen atoms as typical of those of other atoms too, one gets a picture of the structure and the mechanics of our own galaxy. One thus finds the galaxy is much greater than we could see with our optical telescopes, and shows a spiral structure, not quite easily discernible in telescopic observation, and the movements of the spiral arms also can be determined.

There are radiations of other radio frequencies too, from sources which do not radiate in the visible region. Hence a whole new subject has grown up, namely, radio astronomy, which is a powerful supplement to astronomy studied with the optical telescope. One of the exceptionally strong radio sources, for example, has since

been identified as two nebulae colliding and interpenetrating, which obviously must be a very rare event.

Apart from the enormous intrinsic value of the subject, my main interest in giving it here is just to illustrate how rapidly science can grow, and no general description could have given an adequate idea of the growth. Hence I have taken the liberty to present these examples in some detail, and I emphasize again that though selected from branches of science with which I am familiar they are typical of what is happening in all other branches too. The growth may be more or less rapid in the different branches, and the balance between rate of accumulation of new knowledge and the rate of consolidation may be of different magnitudes.

But they all point to the same conclusion, namely, that for various reasons the process of accumulation of new knowledge can be enormously greater than that of consolidation. This is so by the very nature of these two phases in the growth of science. "I never dissuade a man from trying an experiment," says Maxwell, "If he does not find out what he is looking for he may find something else." It reminds me of Alice in the Wonderland asking of somebody for her way. The answer is : "It depends on where you want to go." "I am not particular, " says Alice. "Then you will reach somewhere if you walk long enough," is the profound reply. It should be remembered that the author of *Alice in Wonderland* and of *Alice Through the Looking Glass* was a mathematics don. These books are as much for the scientist and the philosopher as for children.

We have today innumerable bands of scientific workers in all parts of the world who in this sense always reach somewhere, and their contributions to the sum total of

our knowledge is of no mean order. Consolidation of the type that will simplify large branches to a comprehensible and coherent single unit is a rare event. The result has been enormous proliferation and subdivision which gives the man of science some deep concern, which has permeated even into mathematics.

Professor Hilbert expresses this concern forcibly in the following words: "The question is forced upon us whether mathematics is once to face what other sciences have long ago experienced, namely, to fall apart into subdivisions whose representatives are hardly able to understand each other, and whose connections, for this reason, will become ever looser. I neither believe nor wish this to happen ; the science of mathematics as I see it is an indivisible whole, an organism whose ability to survive rests on the connection between its parts." The inevitable has since happened to mathematics too. One is tempted to exclaim : "If gold rusts, what of iron?"

It is true that the frontiers between the different branches of science are continually being broken, but then new ones appear where there was none before. Many hybrid, probably I should say hyphenated, branches grow up like biophysics or radiobiology or paleomagnetism, to mention just a few.

But the main result is that we have today only narrow specialists and no general scientists, barring always a few doubtful exceptions. After all the exceptions are there because according to the proverb they are required to proving the rule. We speak for example of the spectroscopist—pardon me, I am mentioning too big a branch, I should have said either diatomic or polyatomic band spectroscopist or soft X-ray absorption spectroscopist or Lyman

ultraviolet line spectroscopist, or infra-red spectroscopist or X-ray fluorescence spectroscopist.

Even in a narrow branch like thermodynamics I have to specify whether the specialist is an oxide cathodist or a hollow cathodist or a thoriated tungsten specialist. I wish to designate him correctly. He may be just a nuclear spin moment man. With so many legs to walk on, we may some day find ourselves in the position of the centipede of the nursery rhyme, who was asked : "Pray which of your legs do you put forward first when you walk?" The centipede could not answer which, and having been asked the question could not even decide which he should put forward and so could not move.

I read a delightful story related by Lord Moulton, the famous patent law expert who was the chairman of the Dye Stuffs Corporation in the United Kingdom, meeting a German on top of a mountain. "I found"—I quote Lord Moulton—"that he was a chemist and I began to talk on a chemical subject. He told me he was only an organic chemist. Began to talk about coaltar and pharmaceutical products. He then told me he was a coaltar by-product chemist. That did not beat me because I had been just fighting a case of canary yellow. So I slipped into the subject of canary yellow. Still the same ominous silence for a time and then he said, 'I am only a coaltar chemist dealing with blues.' I racked my brain for a colatar blue—I had had to advise on some case— and I gradually slipped into that. Then he finally defeated me, because he said in equally solemn tones, but equally proud of the fact, 'I only deal with methyl blues.' "

Looking back with a certain nostalgia to an earlier age when they were more than mere X 3B or Y 23/56, or some such narrow specialist, one realises that the great

Lord Rayleigh was probably the last complete physicist, just as Poincare was probably the last complete mathematician. I have to go much farther back in history if I have to look for a complete scientist.

It was probably Helmholtz, who started as a great surgeon, was then professor of anatomy in Berlin and later professor of physiology and wrote during that period the two great classics, *The Sensations of Tone* and *Physiological Optics*, then became professor of physics, covered a wide range of physics from energetics to electromagnetism and hydrodynamics, and did some fundamental work on the axioms of geometry. If we wish to look for the complete man, we will have to go very much farther back in history. It may be Leonardo da Vinci.

The scientific literature that is coming out today is so vast that even the specialist cannot keep track of the papers published in the narrow branch in which he specializes. In some branches it has already reached the stage when it may be quicker to solve a problem, starting from scratch, than to consult all the earlier work in the field. So one is not surprised that frequently research papers appear in the journals of learned societies in which some of the results have been anticipated, may be, many years before.

In the earlier days, too, it was not always that scientists read one another's papers; if they avoided reading them it was for a different reason and a more sophisticated one. They did not wish to lapse into habits of vicarious thinking.

The scientist has frequently been accused of using his scientific jargon even when it is not quite necessary. We have the classic example of the professor who, when he had cut his finger, exclaimed, "Dear me, I fear I have excoriated the cuticle of my digit." Joking apart, a person

of the eminence of Faraday while writing to Maxwell does in all seriousness ask the same question: "There is one thing I would be glad to ask you. When a mathematician engaged in investigating physical actions and results has arrived at his own conclusions, may they not be expressed in common language as fully, clearly, and definitely as in the mathematical formulae? If so, would it not be a great boon to such as we to express them so translating them out of their hieroglyphics that we also might work upon them by experiment?" But at least all the specialists could speak the same language and understand one another. Today I am not quite so sure. When the great mathematician Poincare was elected to the Division of Letters of the French Academy, and had the unique distinction of being a member of both the scientific and the literary divisions of the Academy, a wag offered an explanation. It was one of the functions of the literary division to edit the authoritative dictionary of the French language—which they could not have done without the help of Poincare since they could not understand some of the words which he had coined as, for example, automorphic functions. With the present-day specialists coining each his new word, the problem of understanding one another becomes even more acute.

Soon after the last conference on the peaceful uses of atomic energy held in Geneva, I gave a short review in which I said that one of the major achievements of the conference —apart from the large amount of factual information that was exchanged among the various participants— was to have brought on the same platform so many different disciplines, ranging from nuclear physics at one end through radiology, spectroscopy electronics, solid state physics, metallurgy, chemical technology to radiobiology and

genetics at the other end. That is all the contact that one can possibly have today between the different disciplines.

Lest I be misunderstood as drawing a pessimistic picture, I wish to affirm that it is my intention to draw a realistic picture, and if there is any touch of pessimism, it is inherent in the present situation and it is for us to rectify it.

The disabilities associated with the inevitable over-specialization are not peculiar to the sciences. Some of them have been discussed by educationists in connection with single faculty universities. The problems are naturally closely related. The main function of a university is not so much to train specialists or even to impart mere knowledge as to offer a truly liberal education. This can be imparted in many different ways: through the arts, the humanities, or through the sciences. It is very desirable that it is done through all of them. The scientist needs the humanizing influences of the arts and the classics, and the humanists need similarly the disciplining through the sciences before they can claim to have acquired a liberal education. The different sister faculties, the faculty of arts, of science and of engineering, act as very good correctives to one another, and ensure that the education that one acquires is really balanced and integrated, and in any case safeguards against any possible lop-sided development.

It is a little strange, while the scientist readily concedes the need of the humanizing of the other faculties, those in the humanities are not so easily convinced of the need for any disciplining in science. This is unfortunate since purely as a means of acquiring a liberal education the pure sciences have much to offer. What is called the scientific outlook by which I mean the willingness to

face facts squarely and to draw from them logical conclusions, to accept them without any mental or other reservation and to act in a manner that would conform to the conclusions, is a virtue which we all value.

Surely this can be acquired through many different disciplines but more easily and effectively through a scientific disciplining than through the humanities.

So the major problem in education, as in scientific research is to keep the right balance between the different disciplines and the different branches of science.

I have not yet touched on technology. I wish to devote the whole of my concluding lecture to this subject. As I said early in my last lecture, it is one of the major functions of science to gain control or mastery over Nature and use it for the larger good of mankind. Even as a means of acquiring a liberal education some very eminent authorities would place a value on technology. If in addition it is also useful, which all of us concede readily, then it is what I once referred to as double blessedness. One cannot ask for more. I shall deal with them in my next lecture.

III

In my last lecture I dealt with the marked unbalance that at present exists between the rate at which the frontiers of knowledge are expanding and the rate at which the accumulating new knowledge is being integrated or consolidated. The process of integration which makes the sciences more coherent, and easier to comprehend, is naturally a more difficult process, and a much slower process, than extending the boundaries of knowledge. As a result the sciences

get split into numerous narrow subdivisions, and naturally we tend to become narrow specialists and we find it increasingly difficult to understand one another, and we tend even to speak different languages.

I further mentioned at the conclusion of my last lecture that the problems associated with such an over-specialisation are similar to those that have been raised by eminent educationists in connection with the organisation of singal faculty universities. Just as the different disciplines like the humanities, the arts, the sciences and technology in a well-organized university act as correctives to one another, in the advancement of sciences too, the different branches of science not only help each other to grow, but provide the appropriate correctives to one another which are needed for their healthy growth.

Even on the purely educational side, though the scientists and the technologists have always recognized the cultural value of the arts and the humanities, the artists and the humanists do not concede quite so readily the cultural value of even the pure sciences. When it comes to technology, it is rarely that one would even remotely associate with it any such cultural value. This is rather unfortunate. But there is a deep reason for such a misunderstanding.

There is a touching episode in the *Ramayana*, and the scene is laid in the ashram of the great Rishi Atri. The two greatest women of the age, Anasuya and Sita, meet in the ante-room and have a very friendly and warm conversation.

It is a case of kindred hearts meeting and exchanging their inner thoughts. After paying warm compliments Anasuya poses a delicate question. She wishes to know the secret of Sita's being an ideal wife, Sita's answer is very characteristic: "My husband happens to have all the

desirable virtues. I wish he had none of them, to be able to demonstrate that I would continue to love him the same way."

In the same sense, I wish that neither the sciences nor technology had any utilitarian value. Even so they would be worth cultivating for their own sake, for other reasons. Since the case for technology seems harder, I wish to take it up. If the study of even technology is shown to have an educative value, the case for the pure sciences will not need any pleading at all.

Lest I be misunderstood as attempting specious pleading in advocating the educative value of technology, I wish to quote an author whose eminence as a mathematician and philosopher would be sufficient guarantee against any undue leanings towards technology. I am thinking of the late Professor Whitehead. He was a great mathematician, and collaborated with Bertrand Russell in writing that classic book on the foundations of mathematics, *Principia Mathematica*. He was even greater and better known as a philosopher.

Many in the audience here, I am sure, are familiar with his philosophical writings. But few are aware that he was equally great as an educationist. One of his distinguished friends affirms thus in a solemn document (I am quoting him): "From knowledge gained through the years, of the personalities who in our day have affected American university life, I have for sometime been convinced that no single figure has had such a pervasive influence as Professor Alfred North Whitehead." He had spent considerable time and thought on problems of scientific and technical education. His numerous essays and lectures on this subject were published many years ago under the title *Aims of Education*

and they are included in the *Whitehead Anthology*, published recently.

I have read this book several times and I subscribe to his thesis wholeheartedly. Since the thesis, in my opinion, is important and deserves to be much better known, I have been advocating it for some time. I shall quote briefly from what I said on a previous occasion regarding this thesis. As a complement to the Platonic ideal of 'knowledge for its own sake' to which I referred in my first lecture, Whitehead develops the Benedictine ideal of the joy of useful work, and technical education, according to him, is a marriage of the two, which ensures the co-ordination between thought and action, which is essential for the development of an integrated personality. "There can be no adequate technical education which is not liberal", says Whitehead, "and no liberal education which is not technical; that is no education which does not impart both technique and intellectual vision. In simpler language, education should turn out the pupil with something he knows well, and something he can do well. This intimate union of practice and theory aids both."

All that is very refreshing. It fits also with his idea of a university. He does not pose the conventional question whether the function of a university is to educate or to promote learning, but states with a certain freshness, characteristic of him, that the justification for a university is that it preserves the connection between knowledge and the zest of life, by uniting the young and the old in the imaginative consideration of learning. He returns repeatedly in his essays to the problem of keeping knowledge alive, of preventing it from becoming inert, which according to him is the central problem of all education. For successful education there must always be a certain freshness in the

knowledge dealt with and he adds with some sarcasm, which, however, seems appropriate, "Knowledge does not keep any more than fish."

The repeated emphasis laid here on live knowledge reminds me of an incident which Sir Charles Sherrington related in one of his presidential addresses. He recalls as a student, while going for a holiday, having taken with him Darwin's *Origin of Species* with the inspiring words : "It sets the door of the Universe ajar." Other people have arrived at the same goal through a different reasoning. Whether we like it or not, we are in an age of science. If we are to be realistic, if our education is not to be divorced from our environments, if it is to harmonize with the actual life which you and I have to live, scientific and technical education should form an integral part of normal education for not only those who are likely to go in for a scientific or technological career, but for everyone who aims at acquiring a truly liberal education.

I have answered indirectly one major question which should have been raised by me earlier. Why do people take to science ? First, it is part of a liberal education which of course does not finish with leaving school, or even the university. President Roosevelt recalled his calling on Oliver Wendell Holmes Jr. He found him reading Plato's *Dialogues* and he explained that he did it "for the improvement of his mind". He must have been in his eighties then. Secondly, since we are living in an age of science, it is necessary. It is not merely the man of science who needs it but the parliamentarian who legislates for the country, the administrator who helps implement this legislation, and the general citizen who is supposed ultimately to run the government of his country.

Professor Archibald Geikie recalls in his autobiography that he was once dilating on the virtues of castor oil and narrating how an ostrich that had swallowed all sorts of things became ill, and was cured by the administration of castor oil.

A very distinguished statesman, who happened to be present, got interested and enquired: "How did they get it down?" The Professor did not know. "Ah well," said the statesman, "I will tell you how I get it down." Then taking up an empty wine-glass, he proceeded with great gravity to say: "First, I put in a couche of water" (pausing a moment to allow the gathering to comprehend the action), "then I pour in the castor oil" (with another pause as he glanced round to see that they followed him), "and lastly I put another couche of water on the top," smacking his lips with a kind of satisfaction, as he set down the wine-glass again. The Professor then ventured to interpose by asking how he got the upper layer of water to remain above the much lighter oil. The statesman at once saw the dilemma, and with great readiness replied : "Ah, I admit, it requires to be done with great caution."

I said in my first lecture that the obvious way to eliminate misuses of science was to stop the misuses. The agency that can stop them is obviously critical public opinion and informed public opinion, which presumes naturally a certain awareness in the public of the scientific implications. It will therefore be increasingly necessary for the public to be interested in science to be able to discharge their normal responsibilities of citizens. The man of science of course takes to it as he cannot help it; the intense aesthetic and intellectual pleasure that he derives from it would be his adequate reward, if he thinks of reward at all. A good experiment, says Tyndall, while talking

of Faraday, would make him dance with joy. According to Wierstrass, "a mathematician who is not also something of a poet will never be a complete mathematician".

I have reserved to the last the most obvious reason for cultivating science, namely, its application in technology. In the process of understanding nature, which, as I mentioned in my first lecture, is the major objective of science, one incidentally learns also to control Nature. Indeed, these two processes are complementary to each other, and help each other. I shall not attempt to give you the innumerable ways in which one can apply sciences, that is, the innumerable ways in which one can use his knowledge of Nature and his power of control over Nature for general human comfort and welfare. One has merely to point to the advances in medicine, agriculture, rail transport, navigation, air transport, radio communication, the cinema, the television, and the innumerable other scientific marvels which have made modern life so different from what it was in an earlier age.

Indeed these changes have come in so gradually, and unobstrusively, that one is almost tempted to take them for granted, and one rarely remembers the major scientific discoveries that have made these changes possible. In this connection, I generally remind people of their earlier scientific origin by narrating the story of the well-known philosopher Prutkov, a pseudonym under which many Russian writers have expressed some bright sentiments. Prutkov poses the question: "Which is the more useful? The sun or the moon?" He immediately supplies the answer himself, "Of course the moon, because it gives us light during the night, when we most need it." Having thus reminded ourselves of the numerous scientific discoveries that have made enormous change in life, I shall

try to give a few typical examples of how a simple scientific result obtained in the course of trying to understand Nature, without any thought of possible application, has ultimately found far-reaching applications. It would not be an exaggeration if I say that the most extensive and revolutionary applications have always originated from discoveries made without any thought of their probable application.

Take, for example, the discovery of X-rays. In the eighties of the last century there was a very fashionable experiment which was demonstrated in many scientific lectures. It concerned the phenomena accompanying the passage of electricity through rarefied gas in a sealed glass tube. Rontgen observed that some photographic plates that had been lying near the discharge tube, though well covered with black paper and otherwise well protected from light, showed intense fogging. Other scientific workers before him had made the same observation, but the only moral they seem to have drawn from the observation was that it was unwise to leave photographic plates about, when discharge tubes were running.

Rontgen, however, drew a different conclusion. He inferred that the discharge tube, in addition to producing light radiations, which obviously could not reach the photographic plates, produced also other radiations which could penetrate through the black paper and affect the photographic plate. He immediately interposed a purse containing some coins between the discharge tube giving out these radiations, and a fluorescent screen, and could recognise the shadow of the coins on the screen. The penetration of the radiations through the metal coins was not so marked as the penetration through the leather of the purse and hence the shadow. It was this penetrating

power of these radiations, which have since been called X-rays, that attracted his attention first, and it is significant that the first announcement of the discovery was made before a medical society, emphasizing the possible use of these radiations for locating foreign materials in the human body.

Many years later, when Professor Quincke who thought that Lenard should get the credit for the discovery asserted that Lenard had these radiations in mind, it provoked this retort from Stokes: "Yes, Lenard might have had these radiations in his mind, but Rontgen got them into other people's bones." We know how extensively the X-radiations are used now not only for locating foreign matter in the human body, but for innumerable other purposes. Of course, the most important outcome of the application of these radiations was the discovery of an entirely new world, namely, the submicroscopic world of atoms.

Take again the simple observation by Faraday that when a bar magnet was brought suddenly near a closed coil of copper wire, there was a surge of electric current through it. Who would have thought that this observation would form the basis, ultimately, of the generation of electric power, and of the innumerable electrical industries that have grown up around it?

Faraday himself must have at least vaguely realized the large industrial potentialities of this discovery, since when questioned by the Premier about its probable uses, he replied, "Some day you may be able to tax it."

Take again the following simple observation made by Hertz. He found that the violent sparking through the air between two electrical terminals between which was maintained a large difference of voltage generated electric waves which were of the same nature as light, and which

travelled in air with nearly the same velocity but had a much larger wave-length. These are the electro-magnetic waves we use today for radio propagation over great distances over the earth.

The proceedings in this hall are conveyed to the listeners at great distances by such electro-magnetic waves. Radar, used extensively in navigation today for locating neighbouring ships or planes, utilizes just such waves. Only they are of much shorter wave-lengths than used for the radio, since the shorter the waves, the more precise the location. Of course there is a limit to the shortness of the waves that can be used, since the air of the atmosphere does not transmit short waves. Many years ago, Edison observed casually that a metal filament electrically heated in vacua, in addition to giving out thermal radiations, also emits electrons. It was found much later that these electrons can be very effectively controlled by suitably placed electrodes and can be made to perform many uncanny tricks.

These electronic tubes play a ubiquitous part not only in the laboratory, but in almost every industry. Whether it is a cinema, or a television show, air or sea navigation, automatic control, or monitoring in an industry, working of a robot or a calculating machine, one may be sure that the ubiquitous electron is behind it.

I shall cite here just one more example, potentially the most important of them all. Nearly seventy years ago, Becquerel made a very striking discovery. I spoke of the electric discharge tube which had played a major part in the discovery of X-rays. It had been the hunting ground later on for other major discoveries too, like the discovery of the electron. It also played some role, though an indirect one, in Becquerel's discovery. Becquerel was very

familiar with the luminescence exhibited by several minerals, like uranium ores, when irradiated by sunlight. His father had made an extensive study of this phenomenon which is called fluorescence.

Now the X-rays, which attracted the attention of Rontgen, emanated from that part of the glass wall of the discharge tube on which the electron stream generated in the tube was impinging. This part of the glass wall showed also visible fluorescence. Becquerel naturally connected the two phenomena, namely, the generation of X-rays and the production of fluorescence. Since the fluorescence of uranium minerals could be strengthened by exposure to strong sunlight, he conjectured that the uranium mineral so exposed might also radiate strong X-rays. He took, a photographic plate, properly wrapped up in black paper placed on it a specimen of uranium mineral and kept it in sunlight. He could not expose it long, since it became cloudy and continued to be so for several days. The plate and the mineral thus happened to remain in the drawer for several days, and when the plate was developed it showed the imprint of the shadow of the mineral, though the mineral had not been exposed to sunlight at all, or to any strong light. Obviously the mineral had been giving out radiations on its own, which like X-rays, could penetrate through black paper.

The result was the discovery of the phenomenon of radioactivity exhibited by uranium and other elements.

Though natural disintegration of the radioactive element involved generation of energy, no one at the time thought that it could be utilized, since natural disintegration was so slow, and did not proceed long enough, since the end product is lead which is a heavy element, and further the disintegration could not be controlled.

Generation of power from atomic disintegration remained just a dream, till the phenomenon of nuclear fission was discovered. Since my main purpose here is to illustrate how some of the major applications of science are based on discoveries made without any thought of its applications, the discovery of fission forms probably the best example. We are all aware of the enormous consequences, both destructive and peaceful, that have emanated from this simple discovery made in the laboratory in the normal course of trying to understand properly the physics of nuclear reactions.

Lest we get the impression that all major applications emanate from unintended scientific sources, I shall mention immediately the achievement of nuclear fission, though not controllable at present, as a typical example of purposive achievement.

Many years ago, when technology had made her debut, she was welcomed enthusiastically as a handmaid who could minimize the enormous manual labour involved in providing for human needs, human comforts and human welfare. It would leave man with enough leisure to spend on things of human value, like cultivating the arts or the sciences, or other intellectual, cultural and aesthetic pursuits. It was generally estimated that about four hours' work by every man should be adequate for producing all the food, clothing, and other necessities and for providing all the comforts including amenities and reasonable luxuries.

Indeed, the more optimistic among us even estimated the hours of work necessary for this purpose at just two. In a powerful essay published many years ago under the title "*In Praise of Idleness*", Bertrand Russell develops this fascinating theme. After all the main purpose of

technology is just to economise human labour. Just as we talk about the contribution of science to technology, Poincare emphasised the return contribution which technology should make to science. The form in which it would be best appreciated, according to Poincare, is to provide the scientist, just as everybody else, ample leisure that would enable him to cultivate sciences. Bertrand Russell's theme is an elaboration of this. It is not one of the numerous versions of Utopia which one frequently hears about. It was a genuine, realistic, workable proposal.

Many years have passed since then, and technology has improved enormously during this period. Still we are very far from this achievable ideal. One often wonders why the prince's luxuries today are the peasant's demands tomorrow. Our demand for newer luxuries, better and more comfortable transport, better television, in natural colours preferably, better fibres for our clothing, better cosmetics and better everything, may be one of the means of absorbing these extra hours of work. Even the cultivation of the sciences that supply the basic results for technology to feed on is becoming more and more complicated. It was not very long ago that a distinguished visitor from the Continent wishing to see the laboratory of Professor Wollaston was requested to be seated in his drawin room, and the laboratory was brought to him in a tra It consisted of a few lenses, a nicol, a double image pri and some strings and sealing-wax. This string and seali wax tradition was at its best in Faraday's time and c nued even in the time of J. J. Thomson and later of Ru ford too. Some of the early apparatus with which discoveries were made in these laboratories could be up from a few biscuit tins and gadgets of that typ used to speak of the genius in the garret, but tc

muse of science has become much too sophisticated to be wooed under these simple surroundings.

Even the cultivation of the sciences has become an appreciable part of technology.

This may also take a chip out of the leisure that was promised. Even taking all that into account one knows that they can account for all the cut on the promised leisure. The answer obviously is that there must be a tremendous amount of what, from this point of view, should be regarded as non-productive work that we are engaged in.

Sherlock Holmes has taught us an infallible dictum. It is simple: "My dear Watson," says Sherlock Holmes, "when you've exhausted all the other possible alternatives, whatever is left over must be the truth, however improbable it may be."

We find this dictum a useful guide to many branches of physics. On that basis, one occasionally sacrifices at the altar of logic even commonsense. It is on this dictum that I draw the conclusion that there must be an enormous amount of non-productive work that is consuming the leisure we were promised. When we have found that leisure for doing the real things of human value—artistic, cultural or scientific—we can promise ourselves a much better world than we find ourselves in.

I shall conclude my lecture by referring to an incident ...ted by Priestley during the war in one of his broad- ... talks. A woman worker in a factory while going ...r work saw a scholar—a professor—lounging in one ... park seats. She was provoked and asked : ... are you doing, professor, when we are sweating to ...vilisation?" "Madam," came the characteristic ... "I am part of the civilisation you are trying to save"

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